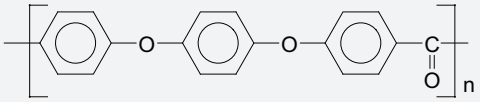
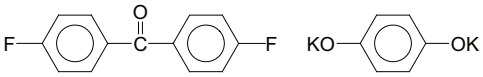
PEEK polyetheretherketone

PARAMETER	UNIT	VALUE	REFERENCES
GENERAL			
Common name	-	polyetheretherketone	
IUPAC name	-	poly(oxy-1,4-phenyleneoxy-1,4-phenylenecarbonyl-1,4-phenylene)	
CAS name	-	poly(oxy-1,4-phenyleneoxy-1,4-phenylenecarbonyl-1,4-phenylene)	
Acronym	-	PEEK	
CAS number	-	29658-26-2; 31694-16-3	
Linear formula			
HISTORY			
Date	-	1962; 1964; 1982	
Details	-	first produced in DuPont laboratories in 1962; ICI chemists synthesized it in 1964; Victrex PEEK commercialized by ICI in 1982	
SYNTHESIS			
Monomer(s) structure	-		
Monomer(s) CAS number(s)	-	345-92-6; 123-31-9	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	218.20; 110.01	
Monomer ratio	-	molar equivalent amounts	
Method of synthesis	-	polycondensation of monomers can be conducted in high boiling solvent (e.g., diphenyl sulfone)	
Temperature of polymerization	°C	280-350	Lu, Q; Yang, Z; Li, X; Jin, S, J. Appl. Polym. Sci., 114, 2060-70, 2009.
Time of polymerization	h	6.5	Lu, Q; Yang, Z; Li, X; Jin, S, J. Appl. Polym. Sci., 114, 2060-70, 2009.
Pressure of polymerization	Pa	atmospheric, under N_2 blanket	
Number average molecular weight, M_n	dalton, g/mol, amu	6,200-15,800	
Mass average molecular weight, M_w	dalton, g/mol, amu	14,300-100,000	
Radius of gyration	nm	15.5-28	Devaux, J; Delimoy, D; Daoust, D; Legras, R; Mercier, Strazielle, C; Nield, E, Polymer, 26, 13, 1994-2000, 1985.

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STRUCTURE			
Crystallinity	%	16-47; 28-44 (yarn); 49 (max); 8.6-19 (with 5% silica)	Welsh, W J; Collantes, E; Gahimer, T, Grayson, M, Antec, 2172-75, 1996; Shekar, R I; Kotresh, T M; Rao, P M D; Kumar, K, J. Appl. Polym. Sci., 112, 2497-2510, 2009; Jaekel, D J; MacDonald, D W; Kurtz, S M, J. Mech. Behavior Biomed. Mater., in press, 2011; Kuo, M C; Kuo, J S; Yang, M H; Huang, J C, Mater. Chem. Phys., 123, 471-80, 2010.
Cell type (lattice)	-	orthorhombic	
Cell dimensions	nm	a:b:c=0.775-0.788:0.586-0.594:0.988-1.007	Karacan, I, Fibers Polym., 6, 3, 206-18, 2005.
Unit cell angles	degree	α:β:γ=90:90:90	
Number of chains per unit cell	-	2	
Crystallite size	nm	3.34-9.50	Karacan, I, Fibers Polym., 6, 3, 206-18, 2005.
Crystallization exotherm	°C	172	Arous, M; Amor, I B; Kallel, A; Fakhafakh, Z, Perrier, J. Phys. Chem. Solids, 1405-14, 2007.
Avrami constants, k/n	-	3.84-6.28	Kuo, M C; Kuo, J S; Yang, M H; Huang, J C, Mater. Chem. Phys., 123, 471-80, 2010.
COMMERCIAL POLYMERS			
Some manufacturers	-	Ensinger; Evonik; Nippon; Solvay; Victrex	
Trade names	-	Ensinger PEEK; Vestakeep; Polypenco; KetaSpire; Victrex PEEK	
PHYSICAL PROPERTIES			
Density at 20°C	g cm^{-3}	1.26-1.4; 1.260-1.267 (amorphous); 1.384-1.401 (crystalline); 1.53 (30% glass fiber); 1.41 (30% carbon fiber)	
Color	-	white	
Refractive index, 20°C	-	1.65-1.77	
Birefringence	-	0.00-0.04 (low crystallinity, 12-20%; 0.10-0.14 (high crystallinity, 30-42%); 0.354 (maximum birefringence for fully crystalline, perfectly oriented fiber)	Bicakci, S; Cakama, M, Polymer, 43, 9, 2737-46, 2002; Karacan, I, Fibers Polym., 6, 3, 206-18, 2005.
Odor	-	odorless	
Melting temperature, DSC	°C	334-350	
Decomposition onset temperature	°C	575	Patel, P; Hull, T R; McCabe, R W; Flath, D; Grasmeder, J; Percy, M, Polym. Deg. Stab., 95, 709-18, 2010.
Thermal expansion coefficient, 23-80°C	$°C^{-1}$	0.43-1.6E-4; 1.9E-5 (30% glass fiber); 5.2-6.7E-6 (30% carbon fiber); 6.69E-4 (melt)	
Thermal conductivity, melt	W m^{-1} K^{-1}	0.25	
Glass transition temperature	°C	143-158	Padey, D; Walling, J; Wood A, Polymers in Defence and Aerospace 2007, Rapra, 2007, paper 15; Arous, M; Amor, I B; Kallel, A; Fakhafakh, Z, Perrier, J. Phys. Chem. Solids, 1405-14, 2007.
Specific heat capacity	J K^{-1} kg^{-1}	2160	
Heat of fusion	kJ mol^{-1}	36.8-37.5	

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PARAMETER	UNIT	VALUE	REFERENCES
Maximum service temperature	°C	315-400	
Continuous use temperature	°C	260	Patel, P; Hull, T R; McCabe, R W; Flath, D; Grasmeder, J; Percy, M, Polym. Deg. Stab., 95, 709-18, 2010.
Heat deflection temperature at 1.8 MPa	°C	155-162; 315 (30% glass fiber and 30% carbon fiber)	
Enthalpy of crystallization	J g^{-1}	18.59-48.72	Kuo, M C; Kuo, J S; Yang, M H; Huang, J C, Mater. Chem. Phys., 123, 471-80, 2010.
Hildebrand solubility parameter	$MPa^{0.5}$	22.8	
Surface tension	mN m^{-1}	21.2-22.6 (calc)	
Volume resistivity	ohm-m	1E14	
Electric strength K20/P50, d=0.60.8 mm	kV mm^{-1}	19	
Coefficient of friction	-	0.22; 0.08-0.09 (lubricated conditions); 0.25-0.3 (dry conditions)	Xiong, D; Xiong, L; Liu, L, J. Biomed. Mater. Res. B, 93, 492-96, 2010.
Contact angle of water, 20°C	degree	90	Zhang, S; Awaja, F; James, N; McKenzie, D R; Ruys, A J, Colloid Surfaces A: Physicochem. Eng. Aspects, 374, 88-95, 2011.
Speed of sound	m s^{-1}	1,860-3,040	Shekar, R I; Kotresh, T M; Rao, P M D; Kumar, K, J. Appl. Polym. Sci., 112, 2497-2510, 2009.
MECHANICAL & RHEOLOGICAL PROPERTIES			
Tensile strength	MPa	75-100; 158-162 (30% glass fiber); 201-223 (30% carbon fiber)	
Tensile modulus	MPa	3,500-4,400; 10,500-10,800 (30% glass fiber); 19,700-20,900 (30% carbon fiber)	
Elongation	%	20-50; 2.7-2.8 (30% glass fiber); 1.7-2.0 (30% carbon fiber)	
Flexural strength	MPa	146-170; 260-261 (30% glass fiber); 317-321 (30% carbon fiber)	
Flexural modulus	MPa	3,700-4,300; 10,400-10,500 (30% glass fiber); 17,500-17,900 (30% carbon fiber)	
Elastic modulus	MPa	3,500-4,000	
Compressive strength	MPa	118-169	
Izod impact strength, unnotched, 23°C	J m^{-1}	no break; 640-850 (30% glass fiber); 640-750 (30% carbon fiber)	
Izod impact strength, notched, 23°C	J m^{-1}	77-91; 69 (30% glass fiber); 64-69 (30% carbon fiber)	
Shear strength	MPa	53	
Poisson's ratio	-	0.4-0.41	Ramani, K; Zhao, W, Antec, 1160-64, 1997.
Shore D hardness	-	88; 91 (30% glass fiber); 92 (30% carbon fiber)	
Rockwell hardness	-	R120	
Shrinkage	%	1.2-1.8; 0.2-1.5 (30% glass fiber); 0.1-1.6 (30% carbon fiber)	
Brittleness temperature (ASTM D746)	°C	-65	
Intrinsic viscosity, 25°C	dl g^{-1}	0.45-1.59	
Melt viscosity, shear rate=1000 s^{-1}	Pa s	380-440; 350 (30% glass fiber)	
Melt index, 230°C/3.8 kg	g/10 min	3-36; 0.7-14 (30% glass fiber); 1.1-11 (30% carbon fiber)	

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PARAMETER	UNIT	VALUE	REFERENCES
Water absorption, 24h at 23°C	%	0.1-0.5; 0.1 (30% glass fiber)	
Moisture absorption, equilibrium 23°C/50% RH	%	0.5	
CHEMICAL RESISTANCE			
Acid dilute/concentrated	-	good	
Alcohols	-	very good	
Alkalis	-	very good	
Aliphatic hydrocarbons	-	very good	
Aromatic hydrocarbons	-	very good	
Esters	-	very good	
Greases & oils	-	very good	
Halogenated hydrocarbons	-	very good	
Ketones	-	good	
FLAMMABILITY			
Ignition temperature	°C	575-595	
Autoignition temperature	°C	595	
Limiting oxygen index	% O_2	35-37.3	Patel, P; Hull, T R; Lyon, R E; Stoliarov, S I; Walters, R N; Crowley, S; Safronova, N; Polym. Deg. Stab., 96, 12-22, 2011.
Heat release	kJ g^{-1}	10.7	Patel, P; Hull, T R; Lyon, R E; Stoliarov, S I; Walters, R N; Crowley, S; Safronova, N; Polym. Deg. Stab., 96, 12-22, 2011.
NBS smoke chamber	Ds	30	
Burninglength	mm	30.9	Patel, P; Hull, T R; Lyon, R E; Stoliarov, S I; Walters, R N; Crowley, S; Safronova, N; Polym. Deg. Stab., 96, 12-22, 2011.
Char at 500°C	%	41-52; 67 (carbon fiber); 63 (glass fiber)	Patel, P; Hull, T R; McCabe, R W; Flath, D; Grasmeder, J; Percy, M, Polym. Deg. Stab., 95, 709-18, 2010; Lyon, R E; Walters, R N, J. Anal. Appl. Pyrolysis, 71, 27-46, 2004;
Heat of combustion	J g^{-1}	22,100-31,480	
Activation energy of decomposition	kJ mol^{-1}	220	Swallowe, G M; Dawson, P C; Tang, T B; Xu, Q L, J. Mater. Sci., 30, 3853-55, 1995.
Volatile products of combustion	-	CO, CO_2, diphenyl ether, phenol, benzene and more	Walters, R N; Hacket, S M; Lyon, R E, Fire Mater., 24, 5, 245-52, 2000; Patel, P; Hull, T R; McCabe, R W; Flath, D; Grasmeder, J; Percy, M, Polym. Deg. Stab., 95, 709-18, 2010.
UL rating	-	V-0 to V-1	
WEATHER STABILITY			
Spectral sensitivity	nm	286, 306, 345	Giancaterina, S; Rossi, A; Rivaton, A; Gardette, J L, Polym. Deg. Stab., 68, 133-44, 2000.
Excitation wavelengths	nm	280, 310	Giancaterina, S; Rossi, A; Rivaton, A; Gardette, J L, Polym. Deg. Stab., 68, 133-44, 2000.

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PARAMETER	UNIT	VALUE	REFERENCES
Emission wavelengths	nm	315, 400	Giancaterina, S; Rossi, A; Rivaton, A; Gardette, J L, Polym. Deg. Stab., 68, 133-44, 2000.
Depth of UV penetration	μm	<250	Nakamura, H; Nakamura, T; Noguchi, T; Imagawa, K, Polym. Deg. Stab., 91, 740-6, 2006.
BIODEGRADATION			
Colonized products		graphite containing composites	
Stabilizers	-	sodium o-phenylphenate	
TOXICITY			
Carcinogenic effect	-	not listed by ACGIH, NIOSH, NTP	
OSHA	mg m^{-3}	5 (respirable), 15 (total)	
Oral rat, LD_{50}	mg kg^{-1}	15,000	
PROCESSING			
Typical processing methods	-	extrusion blow molding, film extrusion, injection molding, mixing, profile extrusion, thermoforming, wire and cable extrusion	
Preprocess drying: temperature/ time/residual moisture	°C/h/%	150/4/	
Processing temperature	°C	355-380	
Additives used in final products	-	Fillers: carbon fiber, glass fiber, graphite, nano-zirconium oxide, PTFE, titanium dioxide; Other: melt stabilizers (e.g., zinc oxide or zinc sulfide, phosphites, phosphonites); Antistatics: fatty quaternary ammonium compounds, quaternary or tertiary ammonium ions and bis(perfluoroalkanesulfonyl)imide	
Applications	-	aerospace, automotive, bearing cages, belts, bolts and nuts, bone screws, butterfly valve seatings, chemically resistant bearings and cams, cryogenic propellant tank for supersonic aircrafts, ducting, electrical (cable ties, cable insulation, rechargeable batteries), film, fracture fixation plates, fuel valves, heat-resistant gears, high performance conveyors, horizontal stabilizers for helicopters, hot melt adhesive, implants, machine tools, medical (compression plates, catheter body, arthroeresis prosthesis, bone substitutes), nuclear power plants, oil/gas, piston rings, pump impellers, satellites, seals, semiconductor wafer carriers, soil well data logging tools, sterilization equipment for medical and dental applications, surgical instruments, tennis racket strings,tubing, vacuum pump blades, valve linings, valve seats	
Outstanding properties	-	chemical and thermal resistance, high strength, wear resistance	
BLENDS			
Suitable polymers	-	PI, PEI, PTFE, PVP, UHMWPE	
ANALYSIS			
FTIR (wavenumber-assignment)	cm^{-1}/-	C=O – 1730; C-O-H – 1120, 1027	Giancaterina, S; Rossi, A; Rivaton, A; Gardette, J L, Polym. Deg. Stab., 68, 133-44, 2000.
Raman (wavenumber-assignment)	cm^{-1}/-	C=O – 1651 (crystalline), 1644 (amorphous)	Stuart, B H; Briscoe, B J, Specrochim. Acta, 50A, 11, 2005-9, 1994.

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x-ray diffraction peaks	degree	18.7, 20.6, 22.9, 28.8	Diez-Pascual, A M; Naffakh, M; Gonzalez-Dominiguez, J M; Anson, A; Martizez-Rubi, Y; Martinez, M T; Simard, B; Gomez, M A, Carbon, 48, 3485-99, 2010.